Effect of Processing High Moisture Ear Corn on Ruminal Fermentation and Milk Yield[1]

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ABSTRACT

Thirty-six multiparous dairy cows (8 fitted with ruminal cannulas) and 16 primiparous dairy cows were blocked by days in milk and parity and assigned to one of four diets containing 53% alfalfa silage [dry matter (DM) basis] plus 1) high moisture ear corn, 2) high moisture ear corn plus expeller soybean meal, 3) ground high moisture ear corn, or 4) ground high moisture ear corn plus expeller soybean meal. The high moisture ear corn was rolled before ensiling at 68% DM. Ground high moisture ear corn was prepared by further grinding through a 9.5-mm screen; grinding reduced the geometric mean particle size from 4.33 to 1.66 mm. Diets contained 1.69 Mcal of net energy for lactation/kg of DM. Relative to cows fed diet 1, milk yield was 4 kg/d greater for cows fed diet 2; numerically, milk yield was about 2 kg/d greater for cows fed diets 3 and 4 than for cows fed diet 1. Yield of milk components also was greater for cows fed diets 2 and 3 but not for cows fed diet 4. Intake of DM and yield of 4% FCM were greatest for cows fed diet 3 and lowest for cows fed diet 1. Digestibilities of DM, organic matter, starch, neutral detergent fiber, and acid detergent fiber were increased, and ruminal NH_3 concentration was depressed, by the grinding of high moisture corn; expeller soybean meal increased ruminal NH_3. Total volatile fatty acid concentration was not different among in vivo treatments, but the molar proportion of acetate decreased, and propionate increased, for cows fed diet 3. The grinding of high moisture corn significantly decreased pH, increased total volatile fatty acid concentration, and increased the rate of decline of NH_3 concentration in ruminal in vitro incubations. Grinding improved the utilization of high moisture corn by lactating cows by stimulating ruminal fermentation.

(**Key words**: high moisture ear corn, grain processing, milk yield)

Abbreviation key: **AS** = alfalfa silage, **ESBM** = expeller soybean meal, **GHMC** = ground high moisture corn diet, **GHMC + E** = GHMC plus ESBM diet, **GHMEC** = ground high moisture ear corn, **HMC** = high moisture corn diet, **HMC + E** = HMC plus ESBM diet, **HMEC** = high moisture ear corn.

INTRODUCTION

Dairy cows cannot achieve high milk yields unless they are fed sufficient energy and protein. Synchronization of energy fermentation and CP degradation is essential for efficient utilization of energy and protein by ruminal microbes. Rapidly degradable carbohydrates have been shown to improve microbial growth in the rumen (17, 28, 38). Alfalfa silage (**AS**) is one of the most common forages fed to dairy cows in North America. During ensiling, much of the CP in alfalfa is degraded to NPN; typically, 50 to 55% of the total N in AS will be in the form of NPN (6). Efficient utilization of NPN in AS for microbial protein synthesis would reduce the need for supplemental RUP. The availability of carbohydrates for ruminal microbes and the host animal are affected by grain source and processing. Because of its starch granule structure (21), corn starch is not extensively degraded in the rumen. The processing of corn improves its digestibility in the rumen and intestine (38). The ensiling of high moisture corn is one of the successful methods to increase its digestibility (16). The grinding of ensiled high moisture corn may have an additive effect on increasing its digestibility (12, 23).

Our hypothesis was that grinding high moisture corn would improve its digestibility, giving rise to greater microbial protein formation from the NPN in AS. Therefore, milk yield would increase, and response to supplemental RUP would decrease, when cows were fed ground high moisture corn.

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MATERIALS AND METHODS

Fifty-two lactating Holstein cows, 36 multiparous (8 fitted with ruminal cannulas) and 16 primiparous [BW, 570 ± 60 kg; milk yield, 36 ± 6 kg/d; parity, 2.6 ± 1.7; and DIM, 110 ± 39 ($\overline{X}$ ± SD)], were blocked by parity and DIM and randomly assigned to one of four diets that were fed as TMR. Nine multiparous cows (2 with ruminal cannulas) and 4 primiparous cows were assigned per diet for a total of 13 cows per diet. The diets (Table 1) contained (DM basis) 53% AS as the sole forage source and either high moisture ear corn (**HMEC**) or ground HMEC (**GHMEC**) as the principal concentrate source. The HMEC was harvested at 68% DM and rolled before being ensiled in upright silos. Just before the once daily preparation of the TMR, GHMEC was ground through a 9.5-mm screen using a hammer mill (Meter/Mill; Clay Equipment Corp., Cedar Falls, IA). Expeller soybean meal (**ESBM**; West Central Coop., Ralston, IA) was supplemented as a source of RUP. The four diets were 1) a high moisture corn diet (**HMC**) containing 42% HMEC, 2) HMC plus ESBM (**HMC + E**) containing 30% HMEC plus 12% ESBM, 3) ground HMC (**GHMC**) containing 42% GHMEC, and 4) GHMC plus ESBM (**GHMC + E**) containing 30% GHMEC plus 12% ESBM (Table 1). After being assigned to diets, cows were fed the same diet throughout the trial. The lactation trial was 12-wk long, starting in May 1994 and ending in August 1994. Cows were housed in tie stalls and were offered feed once daily at 1600 h; orts were recorded once daily. The feeding rate was adjusted daily to yield orts of about 5% of intake on an as-fed basis. The contents of AS, HMEC, and GHMEC in as-fed diets were adjusted weekly based on DM determined at 60°C for 48 h.

Body weights were measured on 3 consecutive d at the start and end of the trial to compute BW change. Cows were milked twice daily, and individual milk yields were recorded. Twelve mean weekly milk yields were computed for each cow. Milk samples were collected at two consecutive milkings (p.m. and a.m.) every 2 wk during the trial and analyzed for fat, protein, lactose, SNF, and SCC by infrared analysis (Wisconsin DHI Cooperative, Appleton, WI) and for milk urea by colorimetric assay (4). Yields of fat, protein, lactose, SNF, and 4% FCM were computed as the weighted means from a.m. and p.m. milk yields on test days and milk composition (n = 6 per cow). Efficiency of feed conversion was computed by dividing both mean weekly milk yield by mean weekly DMI (n = 12 per cow) and biweekly FCM yield by mean biweekly DMI (n = 6 per cow). Efficiency of CP utilization was computed by dividing milk N (protein/6.38) yield by N intake (n = 6 per cow) and by correcting for changes in retained body N by dividing the sum of the mean yield of milk N plus N retained or lost from body tissues [computed from BW change assuming 19% CP in empty BW or 16.2% CP and 2.6% N in live BW; (27)] by N intake (n = 1 per cow).

TABLE 1. Composition of diets.[1]

	HMC	HMC + E	GHMC	GHMC + E
	(% of DM)			
Ingredient				
Alfalfa silage	53.0	53.0	53.0	53.0
High moisture ear corn	41.9	29.9	...	...
Ground high moisture ear corn	...	...	41.9	29.9
Solvent soybean meal	3.5	3.5	3.5	3.5
Expeller soybean meal	...	12.0	...	12.0
$Ca_2(PO_4)_3$	0.6	0.6	0.6	0.6
$NaHCO_3$	0.5	0.5	0.5	0.5
Trace-mineralized salt[2]	0.4	0.4	0.4	0.4
Vitamin premix[3]	0.1	0.1	0.1	0.1
Chemical composition				
CP	16.3	21.3	16.3	21.3
NE_L,[4] Mcal/kg of DM	1.68	1.69	1.68	1.69
NDF	28.2	26.3	28.2	26.3
ADF	19.5	18.7	19.5	18.7
Starch	21.5	14.7	21.5	14.7
OM	93.2	92.6	93.2	92.6
ADIN	6.2	5.7	6.2	5.7

[1]HMC = High moisture corn diet, HMC + E = HMC plus expeller soybean meal, GHMC = ground HMC, and GHMC + E = GHMC plus expeller soybean meal.

[2]Provided (per kilogram of DM) 27 mg of Mn, 27 mg of Zn, 17 mg of Fe, 7 mg of Cu, 0.40 mg of I, 0.30 mg of Se, and 0.10 mg of Co.

[3]Provided (per kilogram of DM) 3880 IU of vitamin A, 730 IU of vitamin D, and 0.73 IU of vitamin E.

[4]Computed from estimated NE_L contents of alfalfa (22) and from NRC (27) tables.

Blood was sampled 4 h after feeding from the coccygeal artery or vein of each cow during wk 5 and 10 of the trial. Blood was heparinized and stored at 2°C for about 24 h; plasma then was prepared and deproteinized with sulfosalicylic acid (4) and stored at –20°C until analyzed for glucose and urea (4). A single fecal grab sample also was collected from each cow at 6 to 12 h after feeding during wk 5 and 10.

Weekly composites of AS, HMEC, GHMEC, TMR, and orts were collected from daily samples of about 0.5 kg each and stored at –20°C; weekly samples of solvent soybean meal and ESBM were collected and stored at 21 to 24°C. The proportion of dietary DM from each ingredient was determined by drying at 60°C (48 h) for AS, HMEC, and GHMEC and at 105°C (3) for ESBM and solvent soybean meal. After drying, ingredients were ground through a 1-mm screen (Wiley mill; Arthur H. Thomas, Philadelphia,

PA). Four 3-wk composites were made from dried ground ingredients by mixing equal amounts of sample. Composites were analyzed for ash and OM (3), total N (Carlo Erba, NA 1500 N Analyzer; Fisons Instruments, Inc., Beverly, MA), and NDF and ADF (31). Determination of NDF was made using heat stable α-amylase and Na_2SO_3 (D. R. Mertens, 1994, personal communication). The ADIN (14) was determined by the macro-Kjeldahl procedure on ADF residue (3) using a copper catalyst (Kjeltabs®; Tecator Inc., Herndon, VA). Starch was determined by the method of MacRae and Armstrong (20) except that amyloglucosidase from *Aspergillus niger* (Sigma A3042; Sigma Chemical Co., St. Louis, MO) was used for hydrolysis of starch and $Ba(OH)_2$ and $ZnSO_4$ were used to deproteinize the samples. Following starch hydrolysis, glucose was determined by glucose oxidase (glucose method no. 510; Sigma Chemical Co.). Indigestible ADF, determined as the ADF remaining after 144 h of in vitro ruminal incubations (10), was used as an internal marker to determine apparent digestibility of nutrients (9). Feces were dried at 60°C for 72 h, ground through a 1-mm screen, and analyzed as described for CP, OM, starch, NDF, ADF, indigestible ADF, and ADIN. Frozen samples of AS were thawed, and water extracts were prepared (25). After pH was measured, water extracts were analyzed for organic acids and ethanol by HPLC [(36); Varian Instrument Group, Walnut Creek, CA]. Extracts were deproteinized and analyzed for total AA and NH_3 (5) and NPN (25).

Four 3-wk composites were made by mixing equal DM (60°C, 48 h) from the freshly thawed HMEC or GHMEC fed in the lactation trial. Duplicate samples of each composite were analyzed for geometric mean particle size using the sieving technique of the American Society of Agricultural Engineers (2). Duplicate composites also were used in two separate in vitro incubations. Enough sample to yield 10 g of DM each from HMEC or GHMEC was weighed into 250-ml spinner flasks (Bellco, Vineland, NJ); 100 ml of McDougall's buffer were added to each flask. The flasks were held at 39°C for 1 h before the addition of the inoculum. Ruminal contents were collected 2 h after feeding from a cannulated lactating cow that consumed 60% AS, 30% cracked corn, and 10% soybean meal (DM basis). An inoculum of strained ruminal fluid enriched with some particle-associated organisms was prepared (10). The temperature of the inoculum was brought to 39°C; 2 m*M* cysteine HCl and 10 m*M* NH_3 were added, and incubations were begun by the addition of 200 ml of inoculum to each flask. Samples were taken every hour from 0 h (immediately after inoculation) to 6 h. Measurement of pH was made directly in the spinner flasks. A 2-ml aliquot of each sample was vortexed with 0.5 ml of 25% TCA (wt/vol); samples were held on ice for 30 min and centrifuged (10,000 × *g* for 15 min at 2°C). Supernatants were analyzed immediately for NH_3 and total AA (5). A 1-ml aliquot of each sample was vortexed with 1 ml of 2.4 *M* $Ca(OH)_2$ and 0.5 ml of 0.4 *M* $CuSO_4$ (36) and centrifuged (10,000 × *g* for 15 min at 2°C); supernatants were stored at –20°C until analyzed by HPLC (Varian Instrument Group) for organic acids. The mobile phase contained 0.015 *N* H_2SO_4, 0.25 m*M* EDTA, and 5% acetonitrile (vol/vol). Flow rate was 0.6 ml/min, and the column temperature was 37°C.

Ruminal contents were taken from the ventral sac of the 8 cannulated cows every 3-wk during the trial (four times total) at 0 h (before feeding) and at 1, 2, 3, 4, 6, 9, 12, 15, 18, 21, and 24 h after feeding. Contents were strained through two layers of cheesecloth, the pH was measured, and ruminal fluid was preserved with H_2SO_4 [final concentration 1% (vol/vol)] or formic acid [final concentration 50% (vol/vol)] and then stored at –20°C. Samples treated with sulfuric acid were thawed and centrifuged (30,000 × *g* for 15 min at 2°C), and the supernatants were analyzed for NH_3 and total AA (5). Samples treated with formic acid were thawed and centrifuged (10,000 × *g* for 40 min at 2°C), and supernatants were sealed in sample vials and analyzed for VFA (7) by GLC (Varian Vista 6000; Varian Instrument Group).

Statistical Analysis

The general linear models procedure of SAS (35) was used for all statistical analyses. A split-plot design was used for analysis of DMI; yields of milk, FCM, and milk components; DM and N efficiencies of milk yield; apparent digestibility; and concentration of milk urea, plasma urea, and plasma glucose. The model was

$$Y_{ijk} = \mu + T_i + \beta_j + \epsilon_{ij} + W_k + TW_{ik} + \delta_{ijk}$$

where Y_{ijk} = dependent variable for diet i, cow j, and week k; μ = overall mean; T_i = effect of diet i; β_j = block for DIM and parity; ϵ_{ij} = whole-plot error (cow within treatment); W_k = the effect of week; TW_{ik} = interaction of diet and week; and δ_{ijk} = subplot error. All ϵ_{ij} and δ_{ijk} were assumed to be independent and normally distributed. Mean separation was by least significant difference, and the main effects of grinding, addition of ESBM, and the interaction of grinding and ESBM were determined by orthogonal contrasts.

A repeated measure model was used to analyze in vivo ruminal NH_3, total AA, VFA, and pH. The model was

$$Y_{ijkl} = \mu + T_i + \epsilon_{ij} + W_k + TW_{ik} + S_{ijk} + H_l + HT_{il} + HW_{kl} + HTW_{jkl} + \delta_{ijkl}$$

where Y_{ijkl} = dependent variable for diet i, cow j, week k, and hour l; μ = overall mean; T_i = effect of diet i; ϵ_{ij} = whole-plot error (cow within treatment); W_k = effect of week; TW_{ik} = interaction of diet and week; S_{ijk} = subplot error; H_l = effect of hour; HT_{il} = interaction of hour and diet; HW_{kl} = interaction of hour and week; HTW_{jkl} = interaction of hour, diet, and week; and δ_{ijkl} = repeated subplot error. All ϵ_{ij}, S_{ijk}, and δ_{ijkl} were assumed to be independent and normally distributed. Mean separation was by least significant difference. A repeated measure model was used to analyze results from the in vitro incubations:

$$Y_{ijk} = \mu + T_i + \beta_j + \epsilon_{ij} + H_k + TH_{ik} + \delta_{ijk}$$

where Y_{ijk} = dependent variable for diet i, incubation j, and hour k; μ = overall mean; T_i = effect of diet i; β_j = effect of incubation (block); ϵ_{ij} = whole-plot error; H_k = effect of hour; TH_{ik} = interaction of diet and hour; and δ_{ijk} = repeated subplot error. All ϵ_{ij} and δ_{ijk} were assumed to be independent and normally distributed. A simple statistical model was used to analyze results from determination of geometric mean particle size; this model included only diet (HMEC or GHMEC) and composite replicate.

RESULTS AND DISCUSSION

Alfalfa silage contained (percentage of total N) 4.0% NH_3 N, 29.2% total free AA N, and 53.8% NPN; pH was 4.8. Organic acid content was (percentage of DM) 0.67% succinate, 6.25% lactate, 0.12% formate, 2.97% acetate, 0.14% propionate, 0.16% ethanol, and 0.21% butyrate. Nagel and Broderick (26) reported lower proportions of NH_3, total free AA, and NPN for their control AS. Higher contents of both NPN and organic acids indicated that fermentation of the AS was more extensive in the present study than in the previous trial (26).

Dry matter intake was highest for cows fed GHMC and lowest for cows fed HMC (Table 2); DMI was greater when ESBM was added as a supplement to unprocessed corn (HMC + E) but was lower when

TABLE 2. Effect of diet on DMI, BW gain, production efficiency, and yield of milk and milk components.[1]

Item	HMC	HMC + E	GHMC	GHMC + E	SE	$P > F^2$
DMI, kg/d	21.2^{b}	22.6^{ab}	23.1^{a}	22.2^{ab}	0.5	0.06
BW gain, kg	12.1	7.5	7.9	15.2	7.5	0.86
Milk yield, kg/d	30.1^{b}	34.0^{a}	32.6^{ab}	32.1^{ab}	0.9	0.03
4% FCM, kg/d	28.6^{c}	31.4^{ab}	31.7^{a}	29.4^{bc}	0.9	0.02
Milk yield/DMI	1.43	1.52	1.42	1.46	0.04	0.25
FCM yield/DMI	1.33	1.38	1.37	1.32	0.04	0.41
Apparent N efficiency[3]	25.5^{a}	20.4^{b}	26.7^{a}	18.8^{c}	0.5	<0.01
Corrected N efficiency[4]	25.9^{a}	20.5^{b}	27.0^{a}	19.3^{b}	0.6	<0.01
Composition, %						
Fat	3.58^{ab}	3.45^{b}	3.75^{a}	3.35^{b}	0.10	0.04
Protein	3.03^{ab}	2.95^{b}	3.17^{a}	2.99^{b}	0.06	0.09
Lactose	4.71^{b}	4.92^{a}	4.93^{a}	4.98^{a}	0.07	<0.01
SNF	8.43^{b}	8.55^{ab}	8.79^{a}	8.66^{ab}	0.12	0.06
Yield, kg/d						
Fat	1.07^{b}	1.18^{a}	1.21^{a}	1.02^{b}	0.03	<0.01
Protein	0.91^{b}	1.01^{a}	1.03^{a}	0.91^{b}	0.02	<0.01
Lactose	1.42^{c}	1.71^{a}	1.62^{ab}	1.53^{bc}	0.04	<0.01
SNF	2.53^{b}	2.95^{a}	2.88^{a}	2.65^{b}	0.07	<0.01
SCC, $\times 10^3$	119	330	152	628	167	0.15
Log (SCC/10^3)	1.95	2.09	1.96	2.13	0.13	0.64

^{a,b,c}Means in rows with no common superscripts differ ($P < 0.05$).

[1]HMC = High moisture corn diet, HMC + E = HMC plus expeller soybean meal, GHMC = ground HMC, and GHMC + E = GHMC plus expeller soybean meal.

[2]Probability of a significant effect of diet.

[3]Milk N/N intake.

[4](Milk N + change in tissue N)/N intake, assuming 19% CP in empty BW or 16.2% CP and 2.6% N in live BW gained or lost (27).

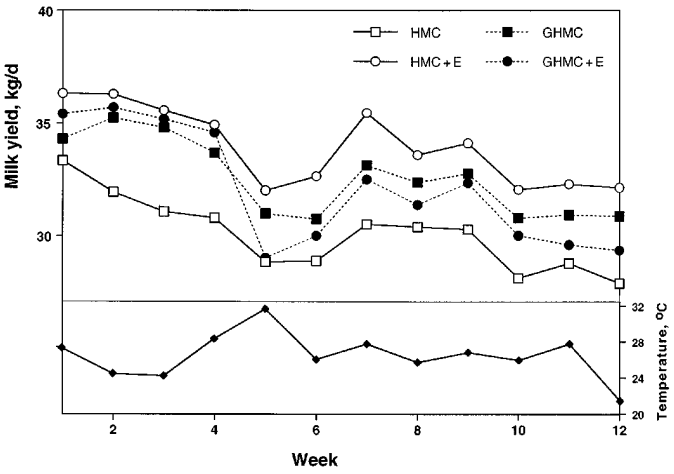

Figure 1. Mean milk yields and daily high environmental temperatures over the 12-wk trial. Diets: high moisture corn (HMC), HMC plus expeller soybean meal (HMC + E), ground HMC (GHMC), and GHMC plus expeller soybean meal (GHMC + E). All diets also contained alfalfa silage.

ESBM was added as a supplement to ground corn (GHMC + E). This interaction of ESBM and grinding was significant ($P = 0.02$). Change in BW was not different ($P > 0.05$) among diets (Table 2) and averaged +10.7 kg over the trial. Mean milk yield was numerically highest for cows fed HMC + E and was significantly greater than that for cows fed HMC (Table 2); milk yield was similar for cows fed the two GHMEC diets and intermediate between yields for cows fed the two HMEC diets. Cows fed HMC did not perform as well as did cows fed the other diets, and their milk yield was only 30 kg/d. Yield of 4% FCM was 31.7 kg/d for cows fed GHMC, which was significantly greater than that for cows fed HMC and GHMC + E (Table 2); difference in FCM yield between cows fed GHMC and HMC was 3.1 kg/d. The main effects of ESBM and grinding were not significant for FCM because of their interaction ($P < 0.01$).

Because of hot weather during wk 5, DMI was decreased, and, hence, milk yield was depressed (Figure 1). After that time, temperature declined, and cows began to adapt to the hot weather; thus, DMI and milk yield recovered. Rodriquez et al. (32) reported that milk yield decreased rapidly when the environmental temperature rose above 29°C. During wk 5 of our trial, daily high temperature averaged 32°C, the highest temperature of the trial (Figure 1). Dairy cows in the northern US generally are not adapted to hot weather and are adversely affected when temperatures increase suddenly. Huber et al. (19) found that diets with high RDP (65.3% of CP) had negative effects on milk yield in hot environments, and diets with high CP (18.4%) in hot environments decreased milk yields and DMI compared with low CP diets (16.1%).

The lower milk yield of cows fed GHMC + E was not expected and might have resulted from the greater incidence of subclinical mastitis in cows fed this diet. Cows fed GHMC + E had numerically higher SCC; however, SCC was not different among diets because of the high variability among cows. Differences among diets also were not significant when SCC data were analyzed after log transformation. This result suggested that only a few cows fed GHMC + E had high SCC, but others had average SCC. High SCC would be expected to decrease milk yield. Cows fed GHMC + E had higher SCC before the trial and, by chance, were assigned to that diet. Moreover, they had a greater increase in SCC during the trial. Cows fed GHMC + E yielded more milk during the first 4 wk of the trial than did cows fed GHMC, but, after wk 5, cows fed GHMC yielded more milk (Figure 1). Efficiency of feed conversion, expressed either as actual milk yield/DMI or FCM/DMI, was not different across diets (Table 2). As expected, N efficiency was greater ($P < 0.01$) for cows fed HMC and GHMC, which were lower in CP, than for cows fed the two diets with added ESBM (Table 2). Cows fed GHMC + E had the lowest N efficiency when expressed simply as milk N/N intake. However, N efficiency of cows fed GHMC + E was not lower than that of cows fed HMC + E when N efficiency was corrected for an assumed amount of N [2.6% N in the difference in live BW; (27)] retained or lost because of change in BW.

Milk fat content (3.8%) was higher for cows fed GHMC than for cows fed the two diets with added ESBM (Table 2); the effect of diet on protein content approached significance ($P = 0.09$), and milk protein content (3.2%) was highest for cows fed GHMC compared with that for cows fed HMC + E and GHMC + E. Milk from cows fed HMC was lower in lactose. A trend also was detected for cows fed GHMC to yield milk with a greater SNF content (Table 2). Cows fed HMC and GHMC + E had lower yields of fat, protein, lactose, and SNF, and cows fed HMC + E and GHMC had higher yields of fat, protein, lactose, and SNF. The interaction of grinding and ESBM was significant ($P < 0.01$). Although used as a source of RUP, ESBM reduced dietary starch content (Table 1), which might have confounded the effects of HMEC processing and RUP supplementation. Protein yield was 120 g/d greater for cows fed GHMC than for cows fed HMC. However, protein yield for cows fed GHMC + E was 100 g/d lower than that for cows fed HMC + E

TABLE 3. Effect of diet on apparent digestibility of dietary components.[1,2]

Item	HMC	HMC + E	GHMC	GHMC + E	SE	$P > F^3$
DM	66.1[b]	64.9[b]	69.7[a]	69.3[a]	1.1	<0.01
OM	66.8[b]	66.0[b]	70.4[a]	70.5[a]	1.0	<0.01
Starch	94.5[b]	93.8[b]	98.7[a]	98.8[a]	0.5	<0.01
NDF	44.2[c]	45.3[b]	47.1[a]	48.0[a]	0.7	<0.01
ADF	44.6[b]	45.1[b]	48.1[a]	48.7[a]	0.6	<0.01
Digestible ADF	87.3	89.2	89.3	91.7	1.2	0.10
CP	65.9[b]	71.5[a]	66.5[b]	73.0[a]	1.1	<0.01

[a,b,c]Means in rows with no common superscripts differ ($P < 0.05$).

[1]HMC = High moisture corn diet, HMC + E = HMC plus expeller soybean meal, GHMC = ground HMC, and GHMC + E = GHMC plus expeller soybean meal.

[2]Apparent digestibility estimated using indigestible ADF as an internal marker (9).

[3]Probability of a significant effect of diet.

and was about equal to that for cows fed HMC. Broderick et al. (6) found that increased RUP in the diet increased yields of milk and protein in cows fed AS. Chen et al. (8) reported that steam-flaked corn improved starch digestibility and improved milk yield by 2.5 kg/d and protein yield by 90 g/d; steam-flaked sorghum improved milk yield by 4 kg/d. Dhiman and Satter (12) found a nonsignificant increase in milk yield of 0.9 kg/d when HMEC was ground. However, Oliveira et al. (29) reported no change in milk yield when steam-flaked sorghum was fed to dairy cows. The processing of grains improves ruminal digestibility (38) but not always milk yield; this difference may be because several factors (e.g., genetics, parity, and climate) can limit milk yield besides rate and extent of energy fermentation and microbial protein synthesis in the rumen.

Apparent digestibilities of DM, OM, starch, NDF, and ADF (Table 3) were greater for cows fed diets containing GHMEC ($P < 0.01$). These results were consistent with other findings that showed that grain processing improves the digestibilities of DM, OM, and starch (8, 29, 34). The elevated CP digestibility that was observed when ESBM was fed was consistent with the typical observation that increasing dietary CP increases apparent digestibility. Improved NDF and ADF digestibility with grinding was unexpected. Lower fiber digestibility would be expected to occur with the lower ruminal pH that likely would accompany the inclusion of more rapidly fermented carbohydrates in the diet. Rapid ruminal fermentation of starch was reported to depress NDF and ADF digestion (11, 28). However, ruminal pH was unaffected by diet in our trial (Table 4). Moreover, Chen et al. (8) found higher NDF and ADF digestibilities for steam-flaked corn than for steam-rolled corn, and Aldrich et al. (1) observed higher NDF and ADF digestibilities in cows fed rapidly fermentable carbohydrates. Mertens and Loften (24) reported that the addition of starch increased lag time and decreased extent of fiber digestion but did not effect rate of fiber digestion in vitro. Grant and Mertens (15) observed that starch addition and low pH decreased in vitro fiber digestion independently of one another. Those researchers (15) suggested that microorganisms that degrade both fiber and starch, such as *Bacteroides succinogenes*, ferment starch preferentially when both are present. Those results (15) are not consistent with the increased digestibility of NDF and ADF observed in the present experiment, but those researchers also mentioned that the effect of grinding on fiber digestion was unknown. Higher NDF and ADF digestion in the present study might have resulted from reduced particle size of the corn spindle, which might have improved digestion of cob fiber.

Blood and milk urea have been used as indices of protein utilization (6). Concentrations of plasma and milk urea were higher for diets containing ESBM. This result was expected because of the higher CP intakes of cows fed HMC + E and GHMC + E. Urea concentrations in plasma and milk (Table 4) were lower for cows fed the ground corn diets than for cows fed the unground corn diets; urea concentrations in cows fed GHMC + E were lower than those in cows fed HMC + E. This result was consistent with improved N utilization from grinding and the greater milk protein yield for cows fed GHMC than for cows fed HMC (Table 2). Oltner and Wiktorsson (30) reported that milk urea was a sensitive index of the dietary ratio of CP to metabolizable energy. Plasma glucose, although numerically higher for the two GHMEC diets, was not different among diets ($P = 0.31$).

Dietary GHMEC depressed ($P < 0.01$) mean NH_3 concentrations over the 24-h sampling period (Table

4), which suggested greater fermentation of GHMEC and increased NH_3 utilization by ruminal microbes than occurred for unground HMEC in the diet. Ruminal NH_3 concentration peaked 3 h after feeding (Figure 2); at that time, NH_3 was lowest (14.8 m*M*) for cows fed GHMC compared with that of cows fed the other three diets ($\bar{X}$ = 22.1 m*M*). The addition of ESBM to the diet increased ruminal NH_3 concentrations, which was reflected in elevated plasma and milk urea concentrations. Total AA concentration was not different among treatments (Table 4). Depressed ruminal NH_3 was consistent with our hypothesis that more rapidly fermented carbohydrates in the diet would improve NH_3 utilization and microbial protein synthesis in the rumen. That milk fat content (Table 2) and ruminal pH (Table 4) were not depressed for cows fed GHMC suggested that the grinding of HMEC did not reduce microbial protein yields because of excessive fermentation rate and depressed ruminal pH (33). Ruminal NH_3 concentrations were significantly reduced in cattle fed steam-flaked corn versus those fed whole corn (34) or greater amounts of ruminally available carbohydrate as high moisture shelled corn (1). Herrera-Saldana and Huber (18) did not observe reduced ruminal NH_3 concentrations when rapidly degradable carbohydrates were fed. Total VFA concentrations were not different (P = 0.61) among treatments (Table 4) and varied with time after feeding (Figure 3). However, the molar proportion of acetate and isobutyrate was lower, propionate was higher, and the ratio of acetate to propionate was lower for cows fed GHMC (Table 4). Herrera-Saldana et al. (17) and Aldrich et al. (1) also found increased propionate and a lower ratio of acetate to propionate in the rumen of dairy cattle fed rapidly degraded carbohydrate.

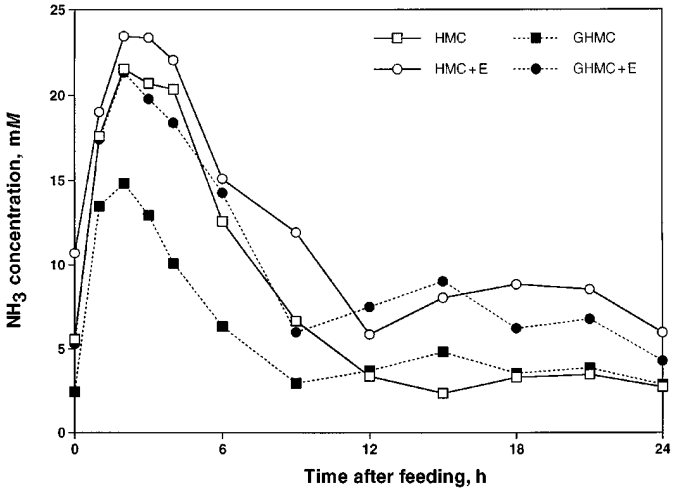

Figure 2. In vivo ruminal NH_3 concentrations over the 24-h feeding cycle. Diets: high moisture corn (HMC), HMC plus expeller soybean meal (HMC + E), ground HMC (GHMC), and GHMC plus expeller soybean meal (GHMC + E). All diets also contained alfalfa silage.

As expected, the grinding of HMEC reduced (P < 0.01) geometric mean particle size (Table 5). Both pH and concentrations of NH_3 declined more rapidly

TABLE 4. Effect of diet on concentrations of milk urea, blood urea and glucose, ruminal pH, and ruminal concentrations of NH_3, total AA, and VFA.[1]

Item	HMC	HMC + E	GHMC	GHMC + E	SE	$P > F^2$
Milk urea, m*M*	4.20[c]	7.50[a]	3.93[c]	6.65[b]	0.18	<0.01
Blood urea, m*M*	4.65[c]	7.81[a]	4.34[c]	6.79[b]	0.19	<0.01
Blood glucose, mg/dl	64.1	62.5	65.6	66.4	1.5	0.31
Ruminal concentrations						
pH	6.24	6.07	6.04	6.09	0.06	0.31
Ammonia, m*M*	10.09[b]	13.60[a]	6.89[c]	11.47[ab]	0.64	<0.01
Total AA, m*M*	3.52	2.04	2.34	2.92	0.50	0.31
Total VFA, m*M*	136.6	148.1	146.6	144.2	6.1	0.61
Molar proportion, mol/100 mol of total VFA						
Acetate (A)	63.9[a]	65.2[a]	59.9[b]	64.0[a]	0.7	0.02
Propionate (P)	20.5[b]	18.6[b]	25.3[a]	20.7[b]	0.9	0.03
A:P	3.18[a]	3.55[a]	2.52[b]	3.14[a]	0.14	0.03
Butyrate	10.9	11.6	10.4	10.9	0.3	0.24
Isobutyrate	1.02[a]	1.00[a]	0.95[b]	1.01[a]	0.01	0.05
Valerate	1.99	1.80	1.70	1.74	0.01	0.45
Isovalerate	1.74	1.80	1.86	1.77	0.01	0.87

[a,b,c]Means in rows with no common superscripts differ (P < 0.05).

[1]HMC = High moisture corn diet, HMC + E = HMC plus expeller soybean meal, GHMC = ground HMC, and GHMC + E = GHMC plus expeller soybean meal.

[2]Probability of a significant effect of diet.

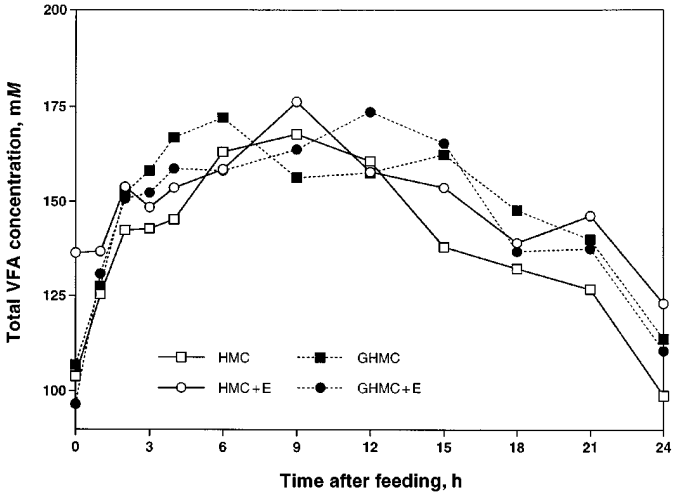

Figure 3. In vivo ruminal concentrations of total VFA over the 24-h feeding cycle. Diets: high moisture corn (HMC), HMC plus expeller soybean meal (HMC + E), ground HMC (GHMC), and GHMC plus expeller soybean meal (GHMC + E). All diets also contained alfalfa silage.

(Figure 4a) and total VFA concentration increased more rapidly (Figure 4b) in ruminal in vitro incubations conducted with GHMEC than in those conducted with HMEC ($P < 0.01$). Mean pH and concentrations of NH_3 and total VFA were altered similarly ($P < 0.01$; Table 5). Although molar proportions of acetate and propionate were not different, there was a small decline in the ratio of acetate to propionate in the incubations containing GHMEC (Table 5). Changes in acetate, propionate, and the ratio of acetate to propionate were more dramatic in vivo (Table 4). A small increase ($P < 0.01$) was observed in total

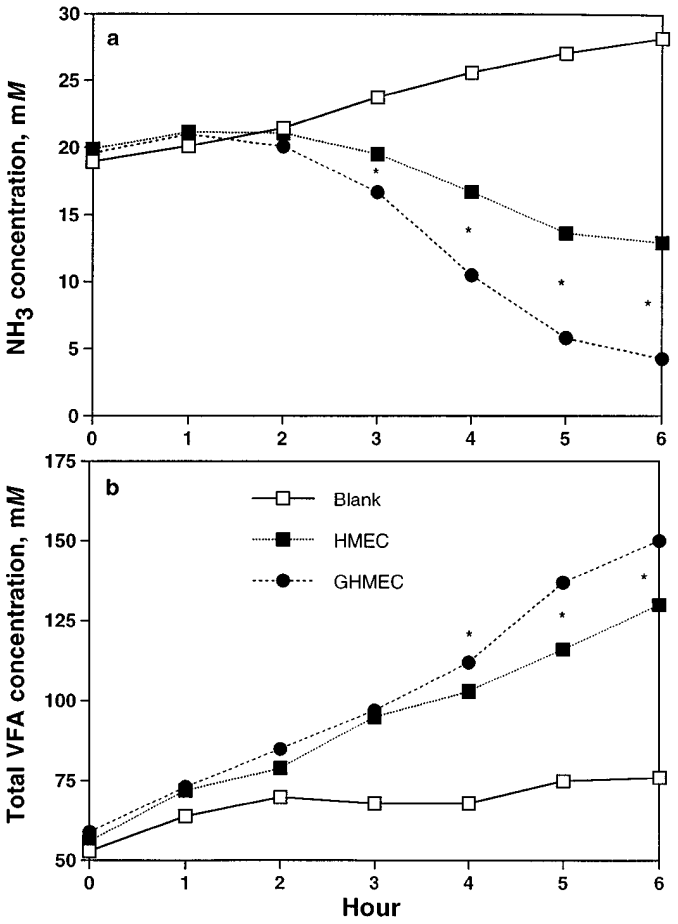

Figure 4. Concentrations of NH_3 (a) and total VFA (b) in ruminal in vitro incubations with blanks (no added carbohydrate) or with added high moisture ear corn (HMEC) or ground HMEC (GHMEC). Times at which there were differences ($P < 0.01$) between HMEC and GHMEC are denoted with asterisks.

TABLE 5. Effect of grinding high moisture corn on geometric mean particle size and on the pH; concentrations of NH_3, total AA, total VFA; and the ratio of acetate to propionate in ruminal in vitro incubations.

Item	HMEC[1]	GHMEC[2]	SE	$P > F$[3]
Particle size, mm	4.33	1.66	0.09	<0.01
NH_3, m*M*	17.85	14.04	0.71	<0.01
Total AA, m*M*	3.95	4.26	0.18	<0.01
pH	6.28	6.08	0.04	<0.01
Total VFA, m*M*	92.9	101.8	1.2	<0.01
Acetate (A), mol/100 mol	64.4	63.4	0.4	0.12
Propionate (P), mol/100 mol	27.1	26.1	0.3	0.09
A:P	2.63	2.40	0.03	0.02

[1]High moisture ear corn.

[2]High moisture ear corn ground through a 9.5-mm screen.

[3]Probability of a significant effect of grinding.

AA when GHMEC was fed (Table 5). These results were similar to in vivo findings that showed increased fermentation rates with processed grains (21). Galyean et al. (13) reported that digestibility of whole corn was lower than that of ground corn, but those researchers did not find any difference in digestibility in steers among corn particle sizes of 8, 5, and 3 mm.

Although lactate was almost nil in the blanks, molar proportions of lactate in 0-h incubations were 5.5% for GHMEC and 4.0% for HMEC; this lactate originated during the fermentation of HMEC in the silo. Lactate decreased rapidly during the in vitro incubations, and none was detected after 4 h. This result indicated that in vitro incubations behaved normally because lactate usually is rapidly catabolized in the rumen in vivo (37).

CONCLUSIONS

Dietary GHMEC as a supplement to AS improved milk yield 2.5 kg/d compared with unground HMEC. The milk yield of cows fed GHMC + E was 2 kg/d lower than that of cows fed HMC + E; however, this difference was not significant and might have been related to the higher SCC of cows fed GHMC + E. Cows fed GHMC had higher yields of 4% FCM, fat, protein, lactose, and SNF than did cows fed HMC. Yields of milk and milk components for cows fed GHMC were similar to those for cows fed HMC + E. The grinding of HMEC increased apparent total tract digestibility of DM, OM, fiber, and starch; depressed in vivo ruminal NH_3 and the ratio of acetate to propionate; decreased plasma and milk urea concentrations; and increased in vitro rates of total VFA formation and rates of decline of pH and NH_3. These findings indicated that the grinding of HMEC increased the rate and extent of ruminal fermentation and improved utilization of NPN in AS by stimulating greater ruminal synthesis of microbial protein. Therefore, GHMEC improved the yield of milk and milk components and the efficiency of nutrient utilization in lactating dairy cows.

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